Healthconomics: trust-based decision-making in the health context discriminates biological risk profiles in Type 1 Diabetes

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Article

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Abstract

Theoretical accounts on social decision-making under uncertainty postulate that individual risk preferences are context-dependent. Generalization of models of decision-making to dyadic interactions in the personal health context remain to be experimentally addressed.

In economic utility-based models, interactive behavioral games provide a framework to investigate probabilistic learning of sequential reinforcement. Here, we model an economic trust game in the context of a chronic disease (Diabetes Type 1) which involves iterated daily decisions in complex social contexts. Ninety-one patients performed experimental trust games in both economic and health settings and were characterized by a multiple self-report set of questionnaires.

We found that although our groups can correctly infer pay-off contingencies, they behave differently because patients with a biological profile of preserved glycemic control show adaptive choice behavior both in economic and health domains. On the other hand, patients with a biological profile of loss of glycemic control presented a contrasting behavior, showing non-adaptive choices on both contexts.

These results provide a direct translation from neuroeconomics to decision in the health domain and biological risk profiles, in a behavioural setting that required difficult and self-consequential decision with health impact. Our findings also provide a contextual generalization of mechanisms underlying individual decision under uncertainty.

1. Introduction

A large array of behavioral studies investigating decision-making under uncertainty have been used to explain individual preference differences through experimental neuroeconomic games involving a difficult choice under ambiguity with money as reward (1; 2; 3; 4; 5). These studies involve the following cognitive processes: option representation, valuation, action selection, outcome evaluation and learning, using update rules.

Some of these studies focus on the valuation system, pointing out how people assign a value to potential rewards and punishments that could result from the choice (based on subjective value; sensitivity to reward; how delayed a reward will be in time). They also consider the factors that may contribute to this computation (payoff, probability, variance, cost/effort, context) (6; 7; 8). Others highlight individual perceptions about outcome probability that could be higher or lower than real outcome (estimation, anticipation risk, error monitoring, prediction error and its frequency) (4). Even more studies are interested in sequential decision-making as risk behavior changes due to probabilistic learning, including the balance between previous choices and experienced outcomes (learning from experience, updating and capacity to decide advantageously with non-conscious bias) (9; 10; 11). Finally, other studies investigate prosocial contexts/situations by keeping some contingencies, relevant to social interactions (12).

Here we address decision-making in the context of self-consequential health issues, which are quite important in Diabetes (13; 14). Individual decision-making is driven by context which is distinct concerning economic investment, or compliance (health investment) to treatment. In both cases, past experiences update by feedback and emotional processes play an important role. As Tarrant et al. (15) suggested the study of patients’ decisions to comply and collaborate in doctor-patient interactions can be envisaged within the framework of interactive decision-making and economic utility models.

Risk-taking and feedback processing in social interactions within the economic domain have been widely studied in distinct populations. It is relevant to consider these concepts also when people engage in risky health behavior and lack avoidance of future complications with high probability. In general, this type of research in traditional approaches highlights individual differences in proneness to maladaptive behavior (3) or suboptimal economic decisions during a repeated interaction trust game in which participants learn to expect different monetary returns through trial-to-trial feedback to choose the most advantageous one to invest. In other words, participant investment (option selection) is based on positive or negative feedback, because the participant is expected to be reciprocated. Similarly, social collaboration or prosocial behavior is less likely to occur continuously if other's behaviors are perceived as unfair or result from norm violation (16; 17).

Importantly, successful decision-making under uncertainty requires adaptive learning as the “ability to estimate expected uncertainty” (related to the variability of outcomes) (18) or correctly infer probabilistic models. So, learning rate is based on the computation of difference between the expected value and the outcome called reward prediction error (RPE). Methodologically, using different reward magnitudes associated with different probability distributions (same mean reward) and with a fixed relative uncertainty over trial to trial allows to estimate the expected uncertainty (standard deviation of a reward distribution – taken as risk) (19). Furthermore, as participants do not now outcome probabilities in advance, their initial decisions are made under complete ambiguity so that they can learn through feedback (20).

These economic utility-based models are limited to contexts of economic decision-making. Here we aimed to generalize this framework to the health domain. Participants (91 adults with type 1 Diabetes) completed two experimental interactive neuroeconomic game tasks, trust games with uncertain decision in economic and health contexts. As decision-making is suggested to be strongly context dependent (21) we expected that different decision-making profiles emerge from both economic and health tasks.

We expected that decision-making profiles are associated with the quality of metabolic control in diabetes. We hypothesized that compliant (trustworthy in dyadic interactions) patients having better metabolic control than non-compliant patients. Furthermore, we hypothesized that both groups (with adequate and non-adequate metabolic control) can learn context contingencies in all tasks, but the control group (with good metabolic control) will consider update values when they are selecting an option, while no significant switching is expected in the group without metabolic control. Third, we aimed to investigate how patient collaboration (health choice) changes faced with different patterns of doctor-patient interaction (feedback) in a trial-and-error feedback processing paradigm.

2. Materials And Methods
A total of 91 volunteers from University Hospital, referred to the clinical assessment of Department of Endocrinology, Diabetes and Metabolism – University Hospital of Coimbra, Portugal ( EDM), were divided in 2 groups according to the dynamics of HbA1c values over time: 42 patients with no glycemic control (mean age: 36.19 ± 8.67, mean educational level: 1.36 ± 0.075) and 49 patients (clinical control group) with glycemic control (mean age: 37.20 ± 9.47; mean educational level: 1.65 ± 0.07). Because metabolic status is considered stable on patients with glycemic control (clinical control group), performance results from a healthy control group (N = 53) are normative and presented as supplementary material (tables S1-S3).

Table 1 summarizes the groups demographic, cognitive/neuropsychological, clinical characteristics, and risk measures. Groups are matched for age, gender, and civil status. Clinicians involved in the consultation at the University Hospital evaluated current and past symptoms and complications. Body Mass Index (BMI) and biochemical data were also collected. To divide groups with or without successful metabolic control, values of HbA1c for the patient consultation history over multiple time points were collected. For the first group (Metabolic Control - MC), we included 1) patients with continuously descending and improving values of HbA1c over time, 2) patients with low (normal) stable/invariant values that did not change beyond 0.5 and 3) patients whose values varied more than 0.5, but the maximum value of this Oscillation was lower than 8.0 (64 mmol/mol). For the second group (No Metabolic Control - NoMC), we included patients with the following dynamic profiles: 1) continuously ascending values of HbA1c over the time, 2) patients with high (abnormal) stable values that did not change beyond 0.5 over the time and 3) patients whose values varied more than 0.5, but the minimum value of this oscillation was more than 8.0.

Participants were asked to completed a number of self-reported questionnaires, validated to Portuguese population, to characterize the sample: the Eysenck Personality Questionnaire (EPQ) (Portuguese version from 22) to evaluate personality traits; Behavior Impulsivity Scale-11 (BIS-11); Translated by 23, validation for the Portuguese population by 24) to evaluate impulsivity in general; DOSPERT (25; 21; Portuguese translation by 26) for individual perception of risk taking assessment in economic and health domains; past and present risk taking to evaluate variations of risk profile across the life span; an intertemporal choice questionnaire, where participants were asked to choose one of three options that differ in risk or sacrifice to delay reward for three different contexts, economic, general health and diabetes specifically (27). In the economic context, participants had to choose between three levels of wait time to win money – more time more money; in general health, participants had to choose between three drugs to avoid possible heart infarct – more effective more secondary effects; in diabetes context, participants had to choose between three number of pricks – more pricks corresponding to delay in long term ocular complications. Finally, the Dutch Eating Behavior Questionnaire (DEBQ) (28; 29) was performed to evaluate three types of eating styles: restrained, external and emotional. Participants also performed cognitive tests with Portuguese population norms, to verify if they could be included in this study: Fluid intelligence (Raven Progressive Matrices) (30), Crystallized intelligence (Vocabulary of WAIS-III) and executive functions such as attentional processes and working memory (Digits Forward and Backward subtests of WAIS-III) (31). Participants aged more than 50 filled out MOCA (Montreal Cognitive Assessment) (32).

Other people in the nuclear family diagnosed with diabetes for at least one year and other current major chronic disease, evidence for past or current history of neurological and psychiatric disorders, recent diseases, major medical illness (cancer, anaemia, and thyroid dysfunction) and severe visual or hearing loss were exclusion criteria. In total, 2 patients were excluded by presenting a history of psychiatric disorder.

2.2 Experimental Interactive Game Decision-making Tasks

As in game theory, each player has a way of acting, the strategy, and actions of two or more decision-makers lead to option selection (33). To mimic this situation, we present two experimental interactive games, named: 1. Computer & Human Mediator Neuroeconomics Experiment and 2. Health Context Interaction Experiment (inspired on the Neuroeconomics framework) (see Figs. 1 and 2).

Risky behaviour in the health context is an option among others with uncertain probabilistic consequence (leading to heath preservation or loss) while in the economic domain is understood as a statistical uncertainty expressed as variance in monetary gain or losses (34). The first experiment refers to situations without a medical context and the second is a tailored task with a medical risk and reward value. It was played in iterated form, where the game is made up of several rounds (runs), repeated 7 times between each type of players. At each trial, participants know with who they are playing through face recognition of the mediator in that run. All trials, 21 in total, require that participants press one of three buttons to indicate their action selection.

Experiment 1: Computer & Human Mediator Neuroeconomics Experiment (Economic Trust Game)

The first game is a classic neuroeconomic experiment and it helps define risk profiles. Participants’ challenge during this trust game was to learn the optimal investment choice based on three mediator’s outcomes. Within three distinct risk alternatives (0 €, 30€ or 50€), they had to choose one (option selection), to wait for respective outcome (feedback) and to indicate how much money they expect to receive from that mediator in the next run (estimate expected uncertainty). Participants were exposed in alternation during the 7 runs for each mediator, which outcome pattern differed in terms of reward distribution (low, moderate, or extreme) for optimal choice. More specifically, each trial was divided into three phases: monitoring phase, decision phase and outcome phase.

The experiment begins with the monitoring phase: the subjects had to indicate an expected value (EU - gain or loss) for the next trial which varies between +20 to +140 answering to the template question. At the first trial, as the participant did not know each mediator payoff contingencies, we can obtain the initial risk profile and learn how the subject initially performed with each mediator (presence or absence of game strategy/planning). In a sequential game, this value (which is then continuously updated) will allow us to calculate the prediction error (PE). Participants had to remember past feedbacks (outcomes) to update
the expected value and decide the next investment for each mediator (estimated expected uncertainty). In that way, we will gather empirical evidence to support different psychological profiles of rational decision-making (Fig. 1).

Experiment 2: Extending Utility based neuroeconomics to the Health Context (Health Trust Game)

The health context interaction experiment, inspired on the classical neuroeconomics experiment, used clinical human mediators. In this second game, we adapted previous experiments to the health context and added a rule/norm: More patient cooperation allowed less waiting time to consultation (less waiting time meaning larger reward). So, we presented one of three different clinicians one at a time which represent three different human mediator feedback as in Game 1 (Low, Moderate and Extreme Rule Following) for optimal choice. In the first phase we presented different health impact levels of developing negative symptoms (for example, diabetic foot) due to impaired glycaemic control. Subjects choose to cooperate (health investment) or not by accepting several therapeutic needle pricks (1 prick meaning No cooperation; 4 pricks meaning Medium cooperation; 6 pricks meaning Highest cooperation) without prior knowledge of the priority reward (amount of time needed to wait for consultation). The final priority outcome rank is a parallel with the final monetary outcome Neuroeconomic Game 1. Note that in this case priority for being received corresponds to low amount's (less time) and in turn to a better outcome. Priority is defined by the number of minutes needed to wait before a consultation (0 to 260). In this game, a computer mediator (available from experiment 1) was not used (Fig. 2).

2.3 Data Analysis

Data were analyzed using IBM SPSS Statistics (v24) (35). Descriptive statistics are reported as mean ± SD. Prior to analysis, raw data were examined for normality by the Shapiro-Wilk goodness-of-fit test (36). Null-hypothesis statistical tests were evaluated according to an alpha value of p = 0.05. The chi-square test was used to compare categorical variables and nonparametric tests (Kruskal-Wallis) were used to compare ordinal variables. To assess possible between group-differences from expected value, investment and feedback, data were submitted to independent sample t-tests. Non-parametric tests, as Friedman tests were applied to analyze differences between expected value, investment, and feedback within each group for the economic and health context, searching for post-hoc differences between mediators. We also performed Friedman test to investigate main effects of the experimental 7 runs for each mediator (M0, M1, M2 and M3) and subsequent post-hoc comparisons

3. Results

We investigated the role of context (economic and health) and risk behavior patterns in diabetic patients as a function of group profile (with and without metabolic control) considering initial decision options and their subsequent update through sequential learning.

Interestingly, self-report measures showed important behavioural differences of the groups defined by the biological partition of metabolic control (for details see Table 1). The group lacking metabolic control showed higher levels of impulsivity, lack of planning, low perception of health risk, high past, and present risk, and intermediate (lower) rewards for health intertemporal choice (more secondary effects). Scales of emotional and external eating behaviour were also significantly different between groups with more external eating behavior for the NoMC group.

Concerning the experimental tasks assessing choice behavior under uncertainty and initial game strategy, we examined the initial risk profile as assessed by initial Decision Phase results. Thereafter, we investigated how participants adjusted decision-making (choice impact) if probabilistic learning feedback is accomplished. For learning achievement, we measured differences on the Expected Value for each mediator, according to mediator feedback payoff contingencies. In this way, we were able to verify if there were different risk profiles according to context and groups and make inferences about learning probabilities and their impact on investment, particularly in the health context, which featured different patterns of doctor-patient interactions in patient compliance. Compliance in this context is seen as a personal investment in health. Table 2 presents results from descriptive statistics of expected value, investment and feedback depending on each mediator (M0, M1, M2 and M3) for both groups in the economic and health context.

3.1 Decision-making under uncertainty (the first play move)

Considering the first play move, we observed distinct profiles. The group with preserved metabolic control (MC) showed a consistent behavior across both contextual tasks and initial strategy (similar investment for all mediators at the first play move- with planning investment). There is an association between initial strategy for both contexts in the MC group [χ² (1) = 5.38, p = 0.02]: subjects tended to be strategically consistent (if they invested the same with all mediators in the economic task, they use the same procedure in the clinical task). We did not find an association between initial strategy for both tasks in the NoMC group (no planning investment).

3.2 Adjusted decision-making during probabilistic learning (sequential play move)

Friedman tests showed a significant main effect of mediator concerning Expected Values, Investment and Feedback, for both groups in both tasks. The exception was that in the MC group there was no mediator effect for investment in the health task. Posthoc tests showed that sensitivity to mediators stemmed mainly from mediators M2 and M3 (the ones that show clear feedback differences in the trust games). (For details see Supplementary material, Table S4).

Concerning changes along the tasks, subjects were able to learn each mediator profile (Monitoring Phase) presenting differences in expected values according to feedback mediator contingencies, expecting to receive more money (economic task) and less waiting time (health related task) from Mediators 2 and 3 (Table 1).
Despite being able to learn mediator feedback contingencies, groups differed in their option for investment in economic and health domains. According to Table 3, patients without metabolic control chose to invest in mediator 3 (M3) whereas in the health context they opted finally for collaborate with Mediator 2 (the clinician than did not violate the norm). In turn, patients with adequate metabolic control (Table 4), revealed no significant preference (or only very marginal) of investment in both contexts. Interestingly, in the health context they opted to collaborate regardless of the doctor payoff contingencies.

4. Discussion

The main aim of this study was to investigate the role of health context (defining patterns of risky behavior) in decision-making under uncertainty in clinical groups where such decisions are extremely relevant, such as in diabetes. This was achieved using trust games, going beyond traditional economic utility-based tasks in economic to health context. By separating different stages of the decision-making process, we gained evidence about feedback processing (update) and how groups differ in considering these update values on subsequent investment. Finally, our findings provide insight in a special form of social decision-making based on patient-doctor interactions and how different payoff contingencies influence differently patient collaboration with and without glycemic control. This enabled to directly relate decision-making profiles with biological status.

Our results extend prior evidence that human decision-making is context dependent (21) in the health domain, while providing clues for its relation with biological outcome. Different decision-making profiles emerged from both economic and health tasks. In the same way, different decision-making profiles emerged from categorical differences in the quality of metabolic control.

Either in initial strategy for investment, each group behaved differently, showing that strategy and planning were related to the adequacy level of metabolic control. Considering iterative decision making, groups behave also differently according to context even though both deal with the same disease (allowing for group matching while differentiating biological outcome). In general, both groups showed to be able to detect payoff contingencies (incorporate feedback processing, updating the experience, (37). However, regarding the health domain, patients without metabolic control seems to be more dependent on external reinforcement than the glycemic control group. Our results suggest that they tend to be more sensitive to putative social norm violations in the clinical setting because patient collaboration changed when faced to different doctors’ payoff contingencies. These results reveal that patients without metabolic control are not indifferent to the patient-clinician relationship, which is a somewhat reassuring finding from this study, despite the non-compliant profile. In contrast, MC patients seem to keep taking good health decision, right from the start, independently of payoff contingencies. Therefore, compliant patients had good metabolic control as we expected. Our pattern of studies could be linked to the statement of Gray et al. (38): “A patient may become ‘stuck’ with a doctor in whom he or she lacks confidence”, with a direct impact on adherence. For clinical practice, this requires counteracting health providers desire to withdraw when patient persist in maladaptive behavior, preventing a non-cooperative or reciprocal circle (39).

Our data supports the notion that risk taking behavior profiles can lead to distinct levels of outcome of a biological variable (in our case glycemic control), suggesting distinct mechanisms of behavioral control. This implies that early detection of these behavioral profiles can enable swift intervention approaches to improve compliance and prevent complications.

5. Limitations And Future Directions

Our results suggest that group differences in learning time (how many runs they need to distinguish payoff contingencies for optimal choice -low, moderate, and extreme) could be further investigated in the future, in particular considering the role of the type mediator. With our experiment, differences in decision phase (investment) were due to context and a biological variable (HbA1C, a measure of metabolic control), but it remains unclear if there are other mediator variables or if contextual cues are ignored or salient depending on other variables.

Despite these shortcomings, the current study could guide future studies on dyadic interactions (as family members current linked by the literature to patient adherence) and neuroimaging approaches. They will be helpful to understand the neural correlates of prediction error (High/Low Expected Value versus Low/High Feedback); the neural correlates of considering update values explaining shifting (High/Low Feedback versus High/Low Investment) and to investigate the neural basis of risk perception and risk taking (High/Low Expected Value versus Low/High Investment). In the health domain, fMRI studies could be advantageous to examine key areas on perceived social norm violation getting insight why perceived health social norm violation (clinician feedback) is more relevant to NoMC group then for the MC group. Finally, further studies could validate intervention programs that promote treatment adherence with training of socioaffective and interaction skills (40).

Conclusion

Through modelling interactive trust games and translating them into the health domain, our findings suggest a strong role of context and biological status in decision-making under uncertainty since different decision-making profiles emerged patients with and without metabolic control. Furthermore, by partitioning different stages of the decision-making process (monitoring, decision, and outcome) we were able to disentangle feedback processing from choice itself getting evidence that probabilistic learning is not enough to explain decision-making in both contexts and groups. These findings also contributed to better understand patient collaboration in reaction to perceived social norm violation in the health domain highlighting a biologically determined decision-making profile and, consequently, proving information that could guide adherence to treatment programs with clinical implications.

Declarations

Author Contributions statement
Designed the study, MCB and HJ, Acquired Data HJ, CB and ICD, Analysis and Interpretation, HJ, MCB, APR and ICD, Wrote Initial Draft HJ, Revised and Approved the manuscript HJ, CB, ICD, APR and MCB

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Conflicts of interest/Competing interests
The authors have no conflicts of interest to declare.

Consent to participate
in the study was obtained according to the Ethics approval by the Faculty of Medicine of the University of Coimbra

Consent for publication
of individual’s data/image. Not applicable

Availability of data and material
Data can be provided by the corresponding author upon reasonable request.

References


**Tables**

**Table 1.** Demographic characteristics, cognitive results, and relevant clinical features and self-report risk measures for NoMC and MC groups (N=91)
<table>
<thead>
<tr>
<th>Variables</th>
<th>MC (N=49)</th>
<th>NoMC (N=42)</th>
<th>$\chi^2$</th>
<th>t</th>
<th>U</th>
<th>gl</th>
<th>p</th>
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<td>Gender (M/F)</td>
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<td>25/17</td>
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<td>Household members (1/2/3)</td>
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<td>16/21/5</td>
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<td>---</td>
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<td>16/17/9</td>
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<td>Vocabulary</td>
<td>32.33 (3.47)</td>
<td>33.60 (2.81)</td>
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<td>---</td>
<td>807</td>
<td>---</td>
<td>0.075</td>
<td>0.034</td>
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<td>Digit Memory</td>
<td>14.82 (2.15)</td>
<td>14.10 (1.92)</td>
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<td>1273</td>
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<td>---</td>
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<td>Disease onset (&lt;18)</td>
<td>24/25</td>
<td>24/18</td>
<td>0.605</td>
<td>---</td>
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<td>17.21 (9.58)</td>
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<td>-0.161</td>
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<td>89</td>
<td>0.870</td>
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<td>HbA1c (%/mmol/mol)</td>
<td>7.19/55 (0.65)</td>
<td>8.52/70 (1.22)</td>
<td>---</td>
<td>6.329</td>
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<td>89</td>
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<td>BMI</td>
<td>24.95 (3.31)</td>
<td>25.20 (3.81)</td>
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<td>989</td>
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<td>89</td>
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<td>10.98 (3.61)</td>
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<td>89</td>
<td>0.005</td>
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<td>54.11 (7.06)</td>
<td>58.05 (8.03)</td>
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<td>0.035</td>
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<td>14.32 (3.76)</td>
<td>17.03 (4.41)</td>
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<td>657.5</td>
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<td>Emotional Eating Behavior</td>
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<td>2.29 (0.78)</td>
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<td>2.84</td>
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<td>89</td>
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<td>External Eating Behavior</td>
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<td>2.58 (0.51)</td>
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<td>0.039</td>
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Educational level (1=12 years, secondary education) 2= university degree or higher; Household income (1=stable; 2=unstable); Members of the Household (1=living alone 2=living as a couple 3=living with children); Residence as distance to health services, in travel time (1=Coimbra; 2=<1h; 3=>1h) RPMT Raven's Progressive Matrices Tests; BMI body mass index. Health Intemporal choice (longer and larger reward; intermediate reward; small sooner reward)

Table 2. Descriptive statistics on economic and health context experimental task for both groups
<table>
<thead>
<tr>
<th>Economic Context</th>
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<th>MC</th>
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<td>SD</td>
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<td>M3</td>
<td>125.91</td>
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Table 3. A Repeated measures comparison of investment between 7th runs for each mediator (Friedman Non-parametric test) on economic and health related context experimental tasks for patients without metabolic control
Table 4. Repeated Measures comparison of investment between 7th runs for each mediator (Friedman Non-parametric test) on economic and health related context experimental tasks for patients with metabolic control

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Figures
Figure 1

Example of economic experimental design considering a run sequence in trustor-trustee interaction. Mediator 1 has a low range for reward. Mediator 2 has an extreme range, reinforcing optimal decision. Mediator 3 has a moderate range, in the middle of M1 and M2 profile (trust investment is reciprocated in a moderate way). Outcome reward also different according to participant option (0, 30 or 50 euros) for all mediators. 1. For “0” option (no risk investment) was received a known low fixed gain (40 euros). 2. For “50 euros” option (risk investment) a low average gain was offered (same mean reward, 40 euros) that could vary from 20 to 60 euros; 3. For “30 euros” option (adjusted risk) a high average gain was earned - low, extreme, and moderate reward: Mediator 1 [35-75]; Mediator 2 [100-140]; Mediator 3 [55-95]. All of them have the same interval (range of 40).
Figure 2

Example of health experimental design considering a run sequence in doctor-patient interaction. Mediator 1 has a low range for reward. Mediator 2 has an extreme range, reinforcing optimal decision fulfilling the pre-established rule. Mediator 3 has a moderate range, in the middle of M1 and M2 profile. Outcome reward also differed according to participant option (1, 4 or 6 pricks) for all mediators. 1. For “4” option (moderate cooperation) a known low fixed gain (160) was received. F or “1” option (no cooperation) a low average gain was offered (same mean reward, 160) it could vary from 120 to 160 minutes. 3. For “6” option (highest cooperation) a high average gain was earned - low, extreme, and moderate – Mediator 1 [90-170]; Mediator 2 [10-90]; Mediator 3 [50-130]. All of them have the same interval [80].

Supplementary Files

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